Effects of Suspended Tailing from the Amax/Kitsault Mine on the Predation Rates of the Marine Zooplankters *Euchaeta Elongata* and *Euphausia Pacifica*

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1985

Canadian Contractor Report of Hydrography and Ocean Sciences No. 21

Fisheries and Oceans / Pêches et Océans

Canada

86-0625/

Canadian Contractor Report of Hydrography and Ocean Sciences

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EFFECTS OF SUSPENDED TAILING FROM THE AMAX/KITSAULT MINE ON THE PREDATION RATES OF THE MARINE ZOOPLANKTERS *EUCHAETA ELONGATA* AND *EUPHAUSIA PACIFICA*

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Cat. No. Fs97-17/21 ISSN 0711-6748

Correct citation for this publication:

Anderson, E.P. 1985. Effects of suspended tailing from the AMAX/Kitsault Mine on the predation rates of the marine zooplankters Euchaeta elongata and Euphausia pacifica. Can. Contr. Rep. Hydrogr. Ocean Sci. 21: 26p.

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ABSTRACT

Anderson, E.P. 1985. Effects of suspended tailing from the AMAX/Kitsault Mine on the predatory feeding rates of the marine zooplankters Euchaeta elongata and Euphausia pacifica. Can. Contr. Rep. Hydrogr. Ocean Sci. 21: 26 p.

We determined the functional responses of two predator/prey systems: the carnivorous copepod Euchaeta elongata feeding on the smaller copepod Pseudocalanus sp. and the omnivorous euphausiid Euphausia pacifica feeding on Artemia nauplii. At the half-saturation prey concentrations (about 20 and 50 prey L^{-1} respectively in 24 hr batch experiments) we presented tailing challenges of 0, 40, 200 and 500 mg L^{-1}. Near the molybdenum mine tailing outfall at 50 m in Alice Arm, British Columbia, 20 mg L^{-1} would have been a high concentration.

In two of four experiments with Euchaeta, and in one of two similar experiments with Euphausia, predation rate was significantly reduced by high tailing concentrations. In both series, high variability among the rates for individual predators obscured the pattern of effects. We modified the design of our final experiment to compare the effects of high tailing and no tailing treatments within individual Euphausia. High tailing clearly depressed the feeding rate of Euphausia on Artemia.

Key words: zooplankton; mine tailings; turbidity; predation; toxicity; Alice Arm, British Columbia

RÉSUMÉ

Anderson, E.P. 1985. Effects of suspended tailing from the AMAX/Kitsault Mine on the predatory feeding rates of the marine zooplankters Euchaeta elongata and Euphausia pacifica. Can. Contr. Rep. Hydrogr. Ocean Sci. 21: 26 p.

Les auteurs ont déterminé les réactions fonctionelles de deux systèmes predateur-proie: le copepode carnivore Euchaeta elongata predateur du plus petit copepode Pseudocalanus sp. et l'euphausiace omnivore Euphausia pacifica, predateur des nauplies de Artemia. Aux concentrations mi-saturees de proies (environ 20 et 50 proies L^{-1} respectivement au cours d'expériences combinées de 24 h), on a effectué des tests de réaction a des stériles aux concentrations suivantes: 0, 40, 200 et 500 mg L^{-1}. Pres de la sortie des stériles de la mine de molybdene, sortie située a 50 m dans le bras Alice (Colombie-Britannique), 20 mg L^{-1} auraient constitué une concentration elevée.

Au cours de deux des quatres expériences avec Euchaeta et d'une des deux expériences semblables avec Euphausia, le taux de prédation était nettement diminué par les concentrations élevées de stériles. Dans les deux series, la variabilité élevée des taux pour chaque prédateur a masqué la régime d'incidence. Les auteurs ont modifié la conception de la dernière expérience afin de comparer les effets de traitment à des concentrations élevées de stériles et en l'absence de ceux-ci chez les individus de Euphausia. Des concentrations élevées ont clairement reduit le taux de consommation de Artemia par Euphausia.

Mots-cles: zooplancton, stériles, turbidité, prédation, toxicité, bras Alice (Colombie-Britannique)

INTRODUCTION

Over most of the ocean, zooplankton form the most significant links between biological processes in the euphotic zone and those in deeper water, including the nutrition of benthos and groundfish. The zooplankton conduit operates both ways: downward as surface production exported as fecal pellets, carcasses and biomass of downswimming animals; upward as upswimming animals carrying with them the effects of their residence at depths which often exceed 100 m. Zooplankton are potential vectors of unwanted effects from subsurface discharges of pollutants to near-surface food webs. We report on laboratory experiments on the predatory feeding of two planktonic crustaceans which migrate between near surface at night and day depths in excess of 100 m. One of the species is the carnivorous copepod Euchaeta elongata; the other is the omnivorous euphausiid Euphausia pacifica.

Alice Arm and Hastings Arm are the innermost reaches of the Observatory Inlet system in northern British Columbia (Figure 1). The central trough of Alice Arm is mostly 300 to 375 m deep, but the deep water is isolated by a sill at 25 m near the junction with Hastings Arm. The AMAX of Canada Limited, Kitsault Mine operated near the head of Alice Arm from April 1981 through November 1982, when operation was suspended for economic reasons. During its first period of activity, the mine discharged about 4.1×10^9 kg of tailing solids through an outfall at 50 m. About 50% of this material would pass a 100 µm sieve. Most of the tailing went directly to the bottom or joined a near-bottom turbidity flow, but about 2% to 8% dispersed in an intermediate plume whose upper horizon was at 65 to 125 m. Particle concentrations in the intermediate plume were always less than 15 mg L^{-1} at a station line 0.5 km seaward from the outfall, and less than 2 mg L^{-1} 4 km seaward (Burling, McInerney and Oldham, 1981, 1983; AMAX, 1982, 1983).

The concern that initiated this study is that most larger zooplankton migrate daily or seasonally through the depth of the intermediate plume. There, they may be affected by the tailing, and transport the consequences to the near-surface food web. Among the resource animals of the upper waters, juvenile salmon on their seaward migrations are notably dependent on zooplankton as food.

A previous field study (Mackas and Anderson, 1985) showed some anomalies of zooplankton distribution at the head of Alice Arm. A subsequent laboratory investigation (Anderson and Mackas, submitted) showed that the tailing would affect zooplankton mortality, feeding, respiration or swimming behavior only at concentrations much higher than those which would be found beyond a few metres from the outfall. In this report, we extend our

inquiry to the predatory feeding of zooplankton. Tailing could reduce predation by direct toxicity to the predator, or by reducing the activity of the prey, or by interfering with the predator's perception of the prey, or by eliciting filter-feeding behavior in omnivores. Tailing could increase predation by making prey easier to capture.

For each of our two experimental species, we had two goals: to determine whether suspended tailing had any effect on predation rate, and if so to determine the mode of action of the tailing.

MATERIALS AND METHODS

A sample of the AMAX/Kitsault tailing had been obtained from the outfall pipe on 14 June 1982. The tailing at the sampling point was about 40% solids. This sample was stored frozen, except for one accidental thaw, until use. Suspensions of the tailing were prepared by diluting 500 mL of the raw tailing with filtered seawater to 2 L in a 2 L graduated cylinder, allowing this to settle for 5 min, and siphoning off the top 1 L. This was divided into smaller portions and refrozen. The large particle fraction at the bottom of the cylinder was discarded; we assumed that this would also have settled rapidly in Alice Arm, and thus have had little effect on zooplankton. The concentration of tailing solids in the working suspension was about 20 mg L^{-1}.

All collections and experiments were performed between 7 March and 21 May 1985, using seawater and animals from Saanich Inlet, B.C.

We collected seawater form 10 m with an all-plastic diaphragm pump. All experiments were run in filtered seawater (FSW) prepared with a low-pressure centrifugal pump and either 0.45 µm membrane filters (Millipore HA) or glass fiber filters (Gelman A/E).

Two representative zooplankton species were selected. both were abundant in Alice Arm and in Saanich Inlet, and both were known to feed on smaller zooplankton in the laboratory. Euchaeta elongata Esterly 1913 is a large (VI female 6.3-6.5 mm total length Fulton, 1968) copepod whose robust mouthparts and maxillipeds, all armed with widely-spaced, strong setae, equip it for exclusive carnivory. We used E. elongata VI females in experiments P1 to P5, 11 March to 19 April. After the first experiment showed that stage of ovary development affected feeding rate, we standardized on VI females with eggs well-developed in ovaries. This stage is easily recognized because the eggs are bright blue. The second species, Euphausia pacifica, is the dominant euphausiid in both Saanich Inlet and Alice Arm. Its variation in abundance contributed strongly to

in abundance contributed strongly to the head-of-inlet anomaly in community structure which we had earlier observed. E. pacifica is an omnivore, but reports vary on its ability to eat large copepods. Ponomareva (1954) reported that the copepod genera Calanus and Metridia were selected over the smaller Oithona in the contents of its "food basket", formed by the thickly setate endopods of the thoracic limbs. Lasker (1966) found that in the laboratory E. pacifica could ingest Artemia nauplii only if the prey were less than 0.8 mm long, which is achieved at about six days post hatch. Artemia nauplii are less active, and their escape reactions feeble, compared to most post-naupliar copepods.

We captured Euchaeta in daytime oblique tows to 120 m with a Reeve net (1 m diameter ring net, 500 µm mesh, large volume acrylic plastic cod end). These tows were made from the MSSV John Strickland on 7 and 18 March. We captured Euphausia in nighttime tows of a 0.75 m diameter net of 300 µm mesh. Tows for Euphausia were hand-hauled from an outboard motorboat at depths of 10-20 m. The green color of the inlet, partial net clogging and, during the last half of the study period, brilliant diffuse phosphorescence, indicated that a phytoplankton bloom was in progress. We towed for Euphausia on 27 April and 4,7,9 and 16 May. The catch of Euphausia became increasingly sparse during this time; and the decline was accompanied by an increase in the proportion of a superficially similar euphausiid, Thysanoessa raschii. These euphausiid species were not reliably distinguished in live sorting.

Heath (1977) found that Euphausia pacifica in the Strait of Georgia and Saanich Inlet were mostly from early spring cohorts. Females, which are dominant in the larger size classes, reach a length plateau at about 15-16 mm during the winter of their first year. Around March-April they spawn and begin a second spurt of growth which takes them to a second plateau at about 20-21 mm in the late fall and winter of their second year (Heath, 1977, Figure 20). Maximum life span is about 23 months. There is a second, less intense, spawning in the fall, presumably involving only the age 1+ cohort. Our Euphausia fell within the range 13.6-18.6 mm: animals just entering their second year. At this stage, survival should be about 60% per month (Heath, 1977, Table 9). Therefore mortality does not account for the scarcity of Euphausia in our tows. With the equipment at hand, we were unable to distinguish between such possible causes for the scarcity as increased night depth, change in horizontal distribution and increased avoidance.

Our first choice for prey was Pseudocalanus sp. (probably several species, total lengths 1.2-2.0 mm, Fulton, 1968). Pseudocalanus is the commonest pelagic copepod species in both Alice Arm and Saanich Inlet. Copepodid VI females were selected without optical aids from the same tows as the predators. Some copepod V were included, but occasional contaminants from

other genera such as Paracalanus and Aetidius were removed when the prey were checked in groups of five under a stereomicroscope. We used Pseudocalanus as prey in all Euchaeta experiments. We also offered Pseudocalanus to Euphausia, but when we found that Euphausia took Pseudocalanus only when this prey was very abundant, we substituted Artemia nauplii (Artemia Inc., mostly 2-4 days post hatch). The Artemia were not fed. They began to die off at 5 days post hatch, or about 7 days if kept at 10 °C. We used only active Artemia.

Experimental animals were kept in a cold room at 10 °C except when being examined or manipulated to initiate an experiment. They were sorted with wide-bore glass pipets. The predators were reduced to a standard state by isolating each experimental animal in 500-1000 mL of FSW for 18-24 hr before the experiment. The cold room was lit on a 12/12 hr light/dark cycle (6/18 for Experiments P12 and P13). The source was a 25 W blue-colored incandescent lightbulb directed at the white ceiling of the cold room. This gave diffuse light at an intensity above the dark-adapted human threshold for clear vision, but below 10^{13} quanta sec^{-1} (about 40 $\mu W\ m^{-2}$ at 475 nm), the minimum that we were equipped to measure. All feeding experiments ran for 24 ± 0.5 hr. Euchaeta experiments were run in 1 L glass jars with polyethylent lids; Euphausia in 2 L jars. The jars were rolled continuously about their long axes at about 1 rpm to keep the animals and tailing in uniform suspension.

At the end of each experiment, the prey were sieved off on 150 µm mesh and counted. Euchaeta occasionally left partially eaten Pseudocalanus. These carcasses were scored separately but included in the total missing and presumed eaten. Euphausia always took entire Artemia.

RESULTS

EUCHAETA

Functional response of Euchaeta elongata to various concentrations of Pseudocalanus sp.

In Experiment P1 (11 March, collection of 7 March) we presented from 5 to 100 Pseudocalanus to each of 14 Euchaeta in 1 L FSW. The 24 hr feeding rates for male, moribund and copepodid V predators were below those for VI females with eggs in ovaries (Figure 2). We chose Euchaeta VI female with eggs well-developed in ovary as the standard stage for all further experiments. Because our results were in good agreement with those of Yen (1983), which are based on more trials, we accepted her determination of the functional response curve. We chose the half-saturation concentration, about 20 Pseudocalanus L^{-1} as the standard prey concentration because we thought that this would produce good sensitivity in the response variable whether the toxic challenge acted to make the prey harder to capture

(lowered slope at lowered tailing concentration) or acted more generally to reduce satiation feeding level.

Response of Euchaeta feeding rate to tailing concentration

In Experiments P2 through P5 we tested the effect of tailing at 0, 40, 200 and 500 mg L^{-1} on the predation rate of Euchaeta (Figures 3 to 6). In Experiment P2 (19 March, collection of 7 March) we saw an average predation rate lower than expected: 4.6 ± 0.7 prey day^{-1} (mean ± standard deviation, compare Figure 2). Experiment P2 indicated that tailing depresses feeding rate (regression slope -8.6×10^{-3}, $p < 0.01$). Experiment P3 was a rerun of P2 using the same predators left in their tailing suspensions with about 20 Metridia pacifica as food for five days, transfer to fresh tailing suspensions for 24 hr and the repeat experiment on the seventh day. Our purpose was to discover whether prolonged exposure to tailing would debilitate Euchaeta. Average predation rate increased to 13.1 ± 0.8 prey day^{-1}. No Euchaeta died, and there was no pattern in the response to tailing treatments.

Experiments P4 and P5 (27 and 30 March, collection of 18 March) were essentially a repeat of P2, P3. In both P4 and P5 the mean predation rates (P4, 12.5 ± 1.0; P5, 13.5 ± 0.7) were similar to that of P3. P4 showed no trend in response to tailing. At the start of P5, the predators had been in tailing for three days. Here the effect of tailing was to reduce predation rate (regression slope -8.8×10^{-3}, $0.01 < p < 0.025$).

EUPHAUSIA

Functional response of Euphausia pacifica to various concentrations of Pseudocalanus sp VI females and Artemia nauplii

In a preliminary experiment on 1 March we had found that Euphausia pacifica of 14-15 mm total length did not capture appreciable numbers of the copepod Metridia pacifica in 2 L jars. Therefore we sought to determine the functional response to Pseudocalanus, which are considerably smaller. We performed the Euphausia experiments in 2 L jars, which are probably below the optimal size for this large and active species, in order to conserve our small supply of tailing and to limit the effort of sorting prey to one person-day per experiment. The result of Experiment P6 (Figure 7) was unexpected. Very few Pseudocalanus were taken, except at 50 prey L^{-1}, the highest concentration offered. We interpret this as an unnatural situation, perhaps the result of self-excited startle reactions of the prey, and therefore not useful for our purposes. We turned to an alternate prey, Artemia nauplii, which are smaller (0.4-0.6 mm in our experiments), less active and known to be taken by Euphausia.

Experiments P7 (2 May, collection of 27 April and P11 (14 May, collection of 7 May) tested the functional response of Euphausia to Artemia nauplii. The two results are similar (Figures 8,9). From 10 to 100 Artemia L^{-1}, the Euphausia were able to take almost all of the prey present in 2 L; but at 200 prey L^{-1} feeding was strongly reduced. This marked reduction below the saturation level is a curious phenomenon which we had to pass by in favor of our original goals. We chose 100 prey L^{-1} as the standard concentration for tailing challenge experiments. The duration of the experiments would be reduced if necessary to increase the sensitivity of the experiments. By the time of the collection for P11, the proportion of Thysanoessa in our tows was so high, and Euphausia so rare, that continuation of the project would have required either the use of a sampling vessel equipped with a winch or postponement until the fall.

Response of Euphausia feeding rate to tailing concentration

Experiments P8 (8 May, collections of 4 and 7 May) and P10 (12 May, collection of 9 May) were tailing challenge tests. P8 did show a significant decrease in Artemia captures with increasing tailing (regression slope -0.064, $p < 0.01$), but P10 showed no such trend. (Figures 10,11). As in the Euchaeta experiments, the variation in capture rates among individual predators would have obscured any but the most dramatic effects. We suspected that age since capture might influence the variation in predation rate, so we performed an appropriate experiment, P9 (10,13,15 May; collection of 9 May). This experiment did not reveal any trend with age since capture, but it did underscore the high variation in predation rate among individuals.

Because variation among individuals was the factor which most obstructed our progress, we sought to compensate for it by alternating treatments on the same individuals. At the same time, we thought we would increase the sensitivity of the experiment by reducing predator-prey exposure to 4 hr, including 3 hr of "day" and lights off near the time of sunset. There were two treatments in Experiment P12: no tailing (O) and high tailing (H, 500 mg L^{-1}). We presented these treatments to six Euphausia in the sequence H-O-H and to another six , O-H-O. We ran two animals in O-O-O as a control for trend with time. Two jars with Artemia but no Euphausia were carried through the O and H treatments to verify recovery of prey.

We incubated Sub-experiment P12.1 for 4 hr. The results (Table 1) included the (by now) familiar high variability among individuals, but feeding rates were well below the optimum for experimental sensitivity. We considered P12.1 to be a pre-treatment for the remaining sub-experiments, placed the Euphausia in FSW for 18 hr, and resumed the standard protocol of 24 hr starvation preceding each 24 hr prey exposure. Figure 12

is a plot of each individual's performance in Pl2.2 and Pl2.3, showing the number of Artemia eaten at high tailing concentration versus the number eaten at zero tailing. Because the (H)-O-H results are intermingled with the (O)-H-O, we have ignored the order of treatments and subtracted the H result from the corresponding O to give a mean difference of 30.4 ± 6.1 Artemia per day. Euphausia ate more Artemia in zero tailing than in high tailing ($t_{13} = 5.0$, $p < 0.001$).

DISCUSSION

EXPERIMENTAL CONDITIONS VERSUS FIELD SITUATION

Our experimental conditions were a crude representation of nature. The length scale of the captive environment was at most 20 cm while Euphausia migrate daily from near surface at night to over 200 m during the day (Brinton, 1962). Wild zooplankton rarely experience surfaces of any kind, let alone glass walls. The light cycle in the cold room was artificial in color and abruptness of change. Kampa and Boden (1954) found that a deep scattering composed mostly of Euphausia pacifica tracked the $1x10^{-4}$ $\mu W\ cm^{-2}$ isolume over the San Diego Trough. When our experimental light was on, it was brighter than this; and when it was off, it was really off. Compressors near the cold room provided unnatural vibrations. Euchaeta, lacking an image-forming eye, almost certainly detects prey by sensing their vibrations with its first antennae (Yen,1982) as do other copepods (Strickler and Bal, 1973; Landry, 1980). The relative importance of vision, mechanoreception and chemoreception in predation by Euphausia are not known. Large, stalked compound eyes are characteristic of euphausiids, and most emit light from highly developed photophores. Most euphausiids are either carnivorous or omnivorous (Mauchline and Fisher, 1969) and the strict carnivores tend to be those with bilobed eyes and one or more pairs of elongated thoracic limbs (Berkes, 1975). Euphausia is a round-eyed species with uniform thoracic limbs. It is probably not a visual predator. Ambient light is probably most important to Euphausia in the same way as to Euchaeta: as a time-giver for cycles of vertical migration and feeding.

The tailing challenges were quite high relative to those which had been found in Alice Arm during the mine's operation. This is appropriate because our exposures were mostly for one day, versus intermittent exposures over the entire life span (1 yr for Euchaeta, 2 yr for Euphausia) in the wild). While the acute and chronic exposures may work through different mechanisms, in common practice regulations on the allowable concentration of a toxicant are often stated as some small fraction of the concentration which produces an undesirable effect in short-term laboratory tests. For example, Canadian federal and British Columbian provincial regulations limit pulp and paper mill effluent in ocean disposal zones to 0.2% to 0.5% of the salmonid LC_{50} (British Columbia, 1974; Canada, 1971).

DESIGN OF PREDATION EXPERIMENTS

Despite the fact that our experiment included unnatural conditions, we believe that the designs were appropriate. We were not attempting to determine natural predation rates. We wanted only a convenient model of natural predation which would with reasonable realism represent the mechanisms which might be affected by tailing.

Predation experiments with zooplankton in jars are convenient. Our initial prejudice was that they would also be replicable because of the statistical advantages of using large numbers of prey in a homogeneous environment. This was not the case in our experiments, nor should we have expected it to be so, for the results of zooplankton feeding experiments usually have variances far in excess of the expectation based on random variation (examples: Frost, 1972; Mullin, 1979; Lasker, 1966; Yen, 1983). Lasker (1966) found that the 24 hr feeding rates of four individual Euphausia pacifica on Artemia nauplii were not only different overall, but also different in temporal pattern over 2 hr intervals within the 24 hr.

Faced with the fact of large variation among individuals, the experimenter can either work to discover the cause of that variation or adjust the main experiment to accept it (by increasing the number of replicates or increasing the population within a replicate) or cancel it (by comparing the effects of different treatments within individuals). We chose the cancellation strategy for its economy. The designs of future experiments of this type should accommodate high variation among individuals.

We would like to characterize the functional responses of our two predator species in terms of the classical model of invertebrate predation (Holling, 1966). The functional response of Euchaeta to various concentrations of Pseudocalanus is similar to the Holling Type 2 model: capture rate proportional to prey concentration at low prey, with an asymptotic approach to a saturation plateau controlled by a mixture of satiation and handling time. At low prey concentrations the predation rate of Euphausia on Artemia looks like either Type 2 or Type 1 (similar to Type 2 except linear to the plateau). But at high prey we saw an inhibition of predation rather than a saturation plateau. The upper prey concentration offered, 200 L^{-1}, is high, but not ridiculously so. Our efforts to comprehend this functional response are further confused by the results for the Euphausia/Pseudocalanus system. Here, we found appreciable predation only at the highest prey concentration offered, 50 L^{-1}. With imagination this could be interpreted as the low prey end of a Type 3 functional response, one with low or no feeding below some prey threshold. This would indicate an initiation threshold at a very high natural prey concentration. We cannot accommodate both Euphausia responses in a single model.

EFFECTS OF TAILING ON PREDATION BY ZOOPLANKTON

In Euchaeta we have shown that in two of four similar experiments tailing depressed the rate of feeding on a naturally co-occurring prey. We were unable to continue toward our second goal, discovery of the mode of action of the tailing. Euchaeta is sightless and probably detects its prey by vibrations, which would be little affected by tailing. The most likely mode of action of the tailing is to reduce the frequency of encounter between predator and prey by reducing the mean velocity or altering the swimming pattern of either predator or prey. Changes of this sort can be caused by direct toxicity or by changes in in behavior, for example from predatory searching to filter feeding. Some of these mechanisms could cause persistent effects which would be transferred from the depth of tailing exposure to near-surface waters, where the nighttime distributions of predator and prey overlap.

In Euphausia we demonstrated a similar effect of tailing at high concentration. In most of our experiments with Euphausia, and all with Euchaeta, the effects of the factors we hoped to investigate were obscured by high variability among the performances of individual predators. This is apparently a common feature of zooplankton feeding experiments. In the last experiment with Euphausia, we subtracted out the consistent portion of variation among individuals. The interpretation of the result was clear: at high tailing concentration, tailing suppresses the predatory feeding of Euphausia. The potential modes of effect on Euphausia include interference with vision as well as with the two senses (mechanorecption, chemoreception) available to Euchaeta.

Euchaeta is a different sort of predator from Euphausia. The copepod is an obligate predator which probably searches out and pursues prey. The euphausiid takes smaller prey, especially in proportion to its size. Many euphausiids feed on detritus and other relatively large inactive particles such as planktonic eggs (Mauchline and Fisher, 1969). Euphausia pacifica are encounter feeders in the sense proposed by Cushing (1958, 1968) and Conover (1966): they appear to detect larger particles at a small distance and capture these individually rather than by filter feeding. In one large copepod, Koehl and Strickler (1981) have argued that chemosensory detection mediates encounter feeding on large phytoplankton cells. The probability of encounter would be larger for larger prey (Gerritsen and Strickler, 1976) leading to an apparent change in electivity in favor of larger particles (Glasser, 1984). The frequency and probability of encounter for prey of different apparent sizes could be strongly modified by a change in the range of the predator's senses, for example by reducing water transparency or masking scents. The consequent shift in the predator's selectivity could have complex ramifications, for example by

releasing predation pressure on nauplii while causing euphausiids to rely more on phytoplankton as food. Because Euphausia can meet can meet their metabolic needs on phytoplankton plus detritus (Lasker, 1966; Parsons et al., 1967) the effect of tailing on Euphausia predation could appear not in Euphausia numbers but in some other portion of the foood web.

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Experiment			12.2			12.2			12.3			12.2,12.3
Incubation, hr			4			24			24			-
Jar	Predator[1]	Length, mm	Tailing[2]	Live[3]	Eaten	Tailing	Live	Eaten	Tailing	Live	Eaten	0 minus H
15	T	17.9	0	34	66	H	4	96	0	3	97	1
16	E	17.4	0	17	83	H	54	46	0	36	64	18
13	E	16.0	0	95	5	H	55	45	0	13	87	42
9	E	18.0	0	90	10	H	86	14	0	19	81	67
10	E	18.6	0	96	4	H	43	57	0	72	28	-29
32	E	16.1	0	97	3	H	80	20	0	14	86	66
14	E	16.6	0	101	(0)	0	10	90	0	16	84	-
24	E	18.0	0	99	1	0	42	58	0	33	67	-
11	E	17.6	H	76	24	0	70	30	H	62	38	-8
12	E	17.2	H	97	3	0	47	53	H	80	20	33
5	T	18.3	H	99	1	0	5	95	H	74	26	69
8	E	16.3	H	90	10	0	2	98	H	38	62	36
17	T	19.3	H	87	13	0	77	23	H	70	30	-7
25	E	18.5	H	96	4	0	0	100	H	86	14	86
20	-	-	0	99	-	H	100	-	-	-	-	-
6	-	-	0	100	-	H	100	-	-	-	-	-

1. T : Thysanoessa raschii. E : Euphausia pacifica
2. 0 : zero tailing. H : 500 mg tailing solids L^{-1}.
3. Artemia nauplii after incubation

Table 1. Feeding rates of Euphausia in alternating high and low tailing concentrations.

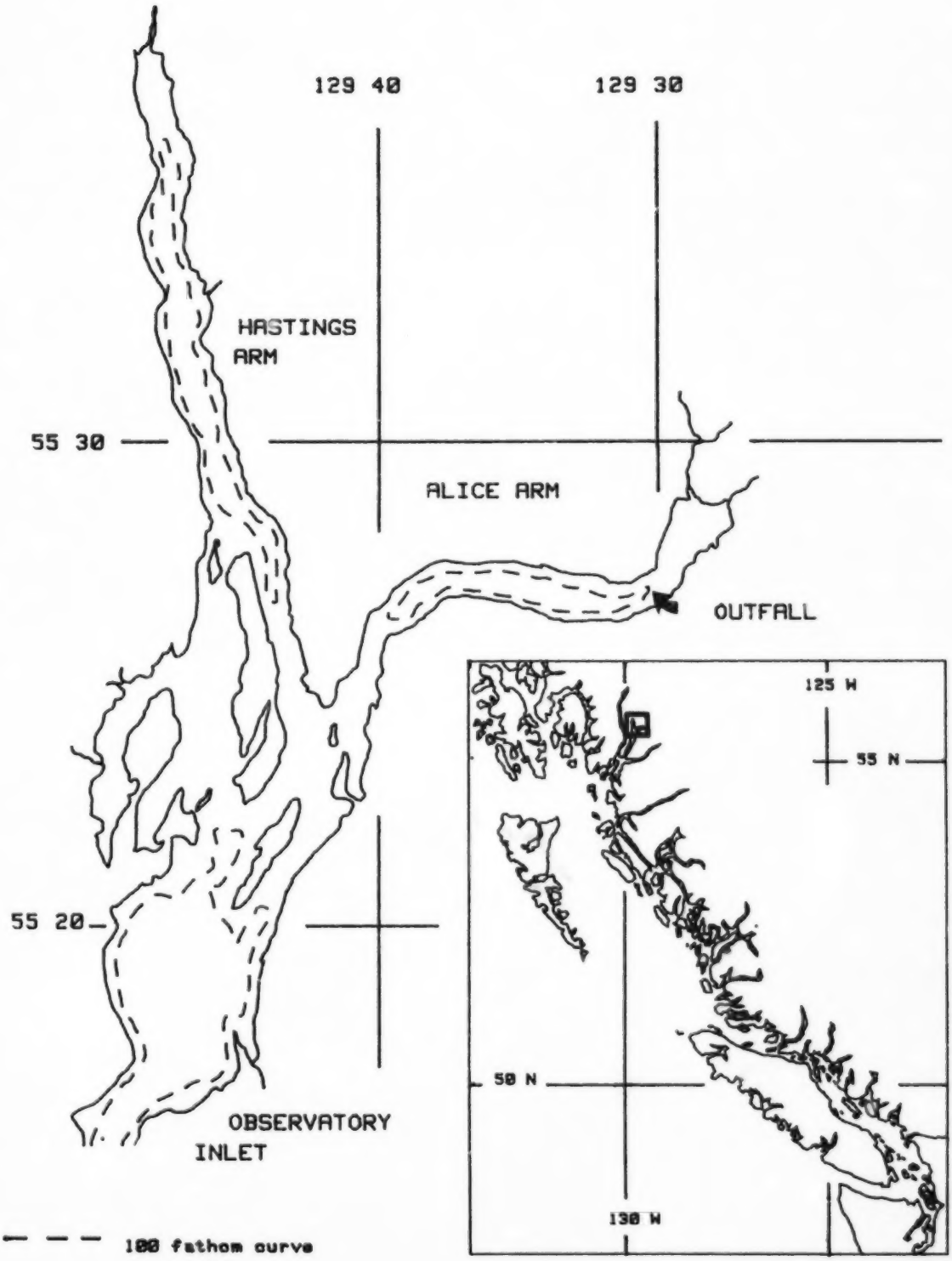

Figure 1. Location of the AMAX/Kitsault Mine tailing outfall.

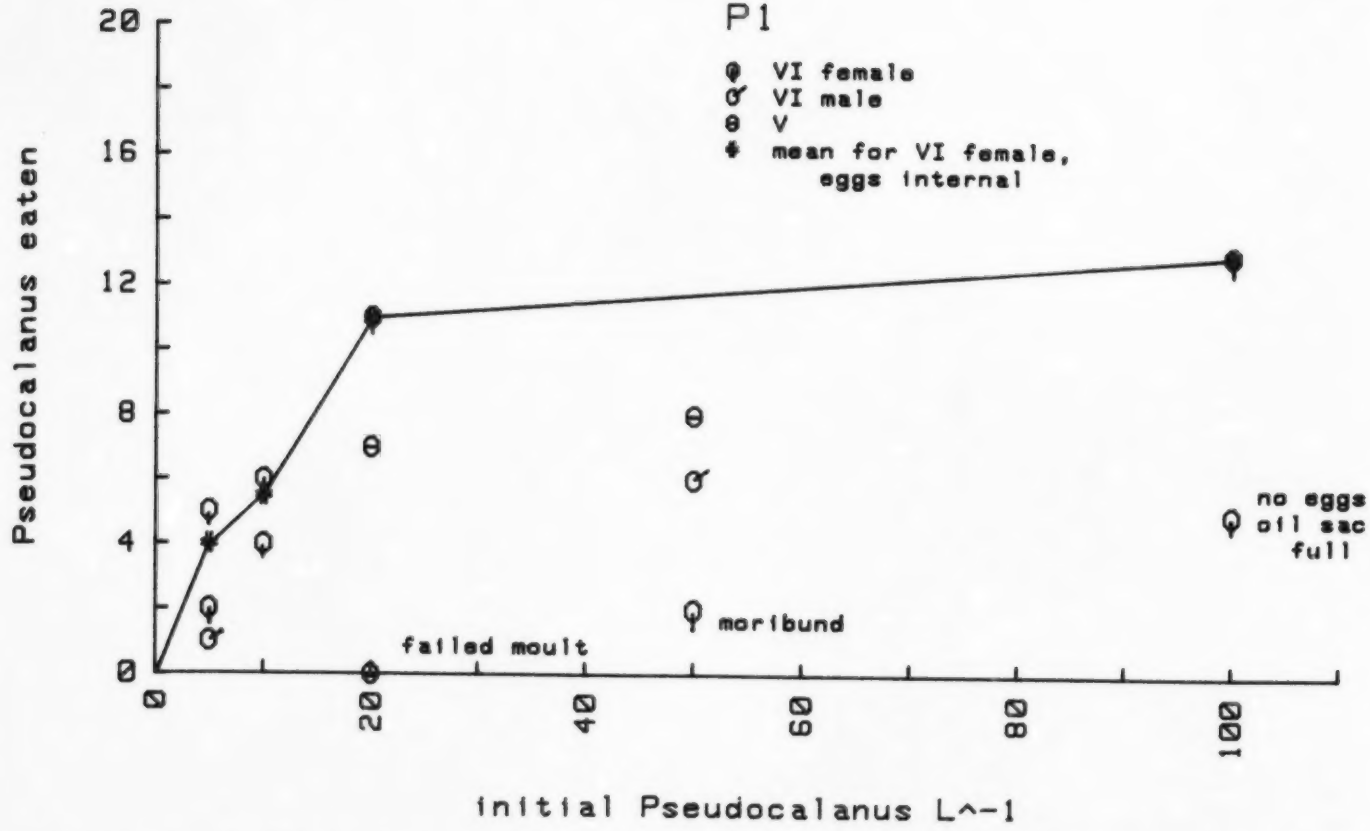

Figure 2. Functional response of Euchaeta elongata to various concentrations of Pseudocalanus sp.

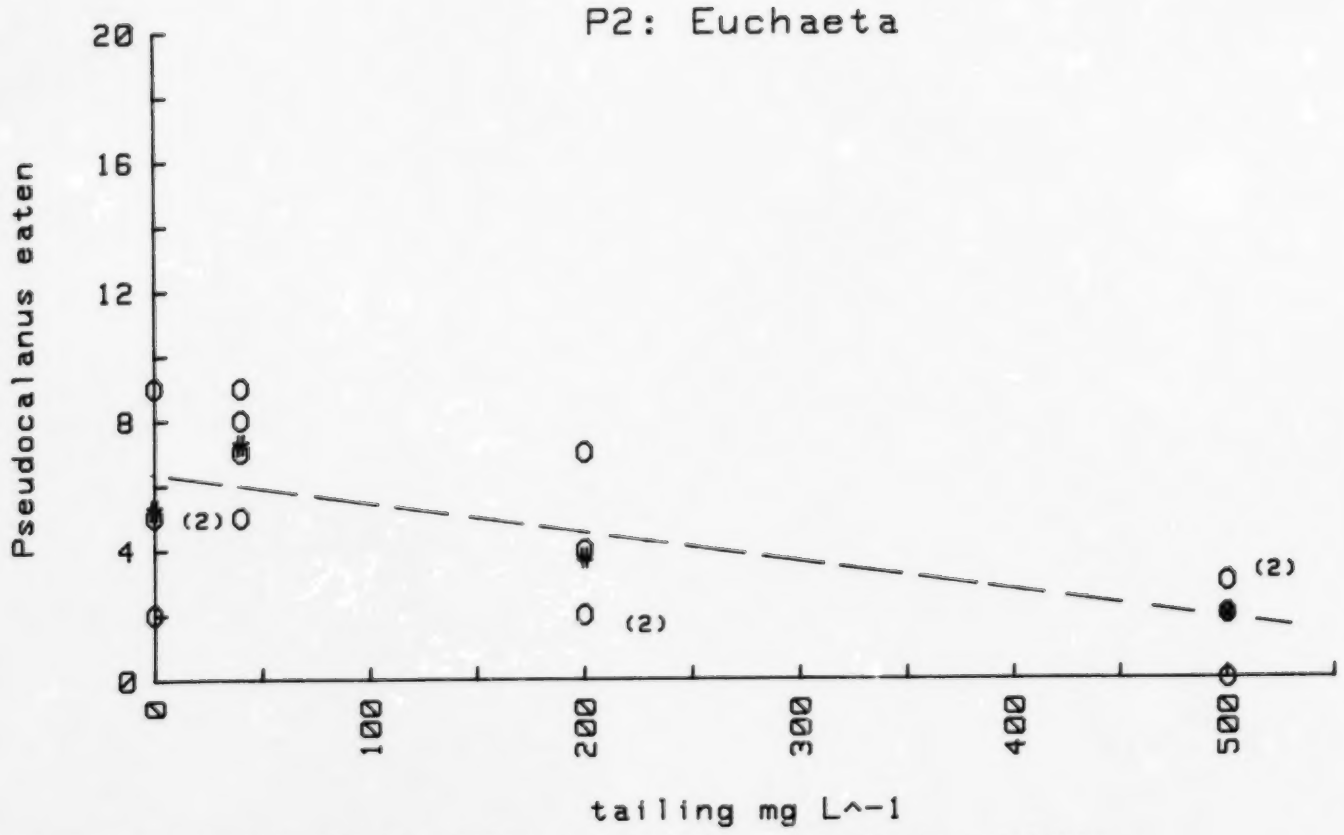

Figure 3. Experiment P2: effect of tailing on Euchaeta predation.

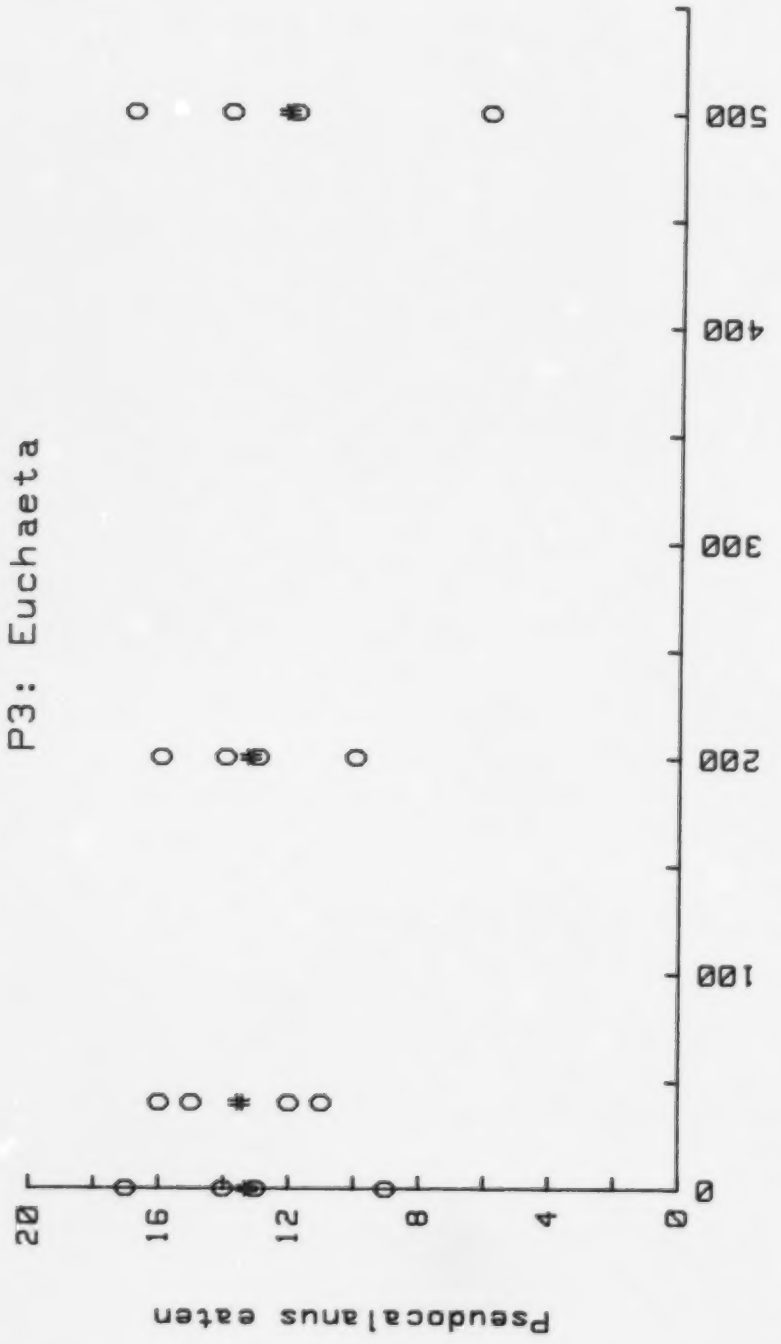

Figure 4. Experiment P3: effect of tailing on Euchaeta predation.

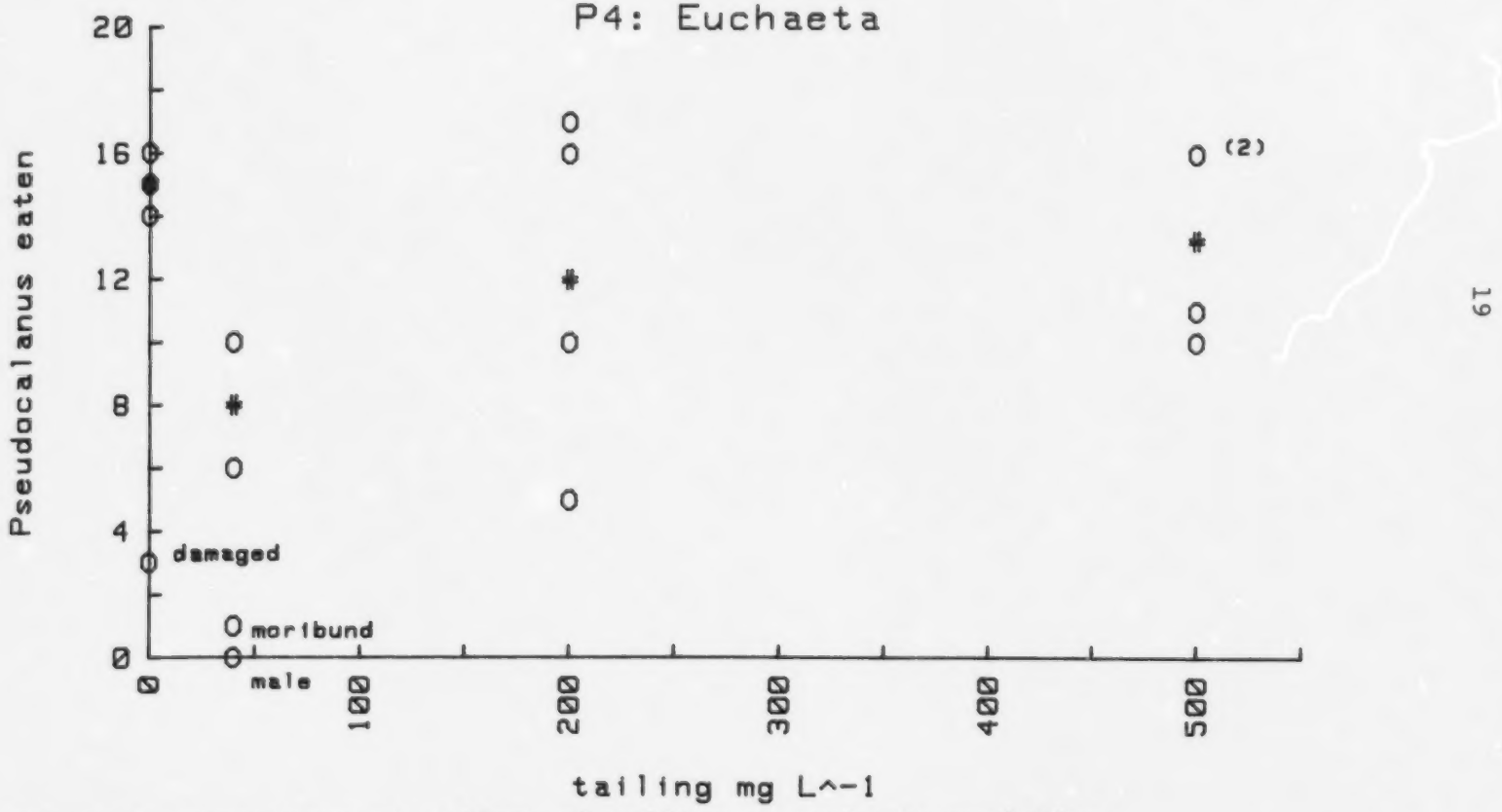

Figure 5. Experiment P4: effect of tailing on Euchaeta predation.

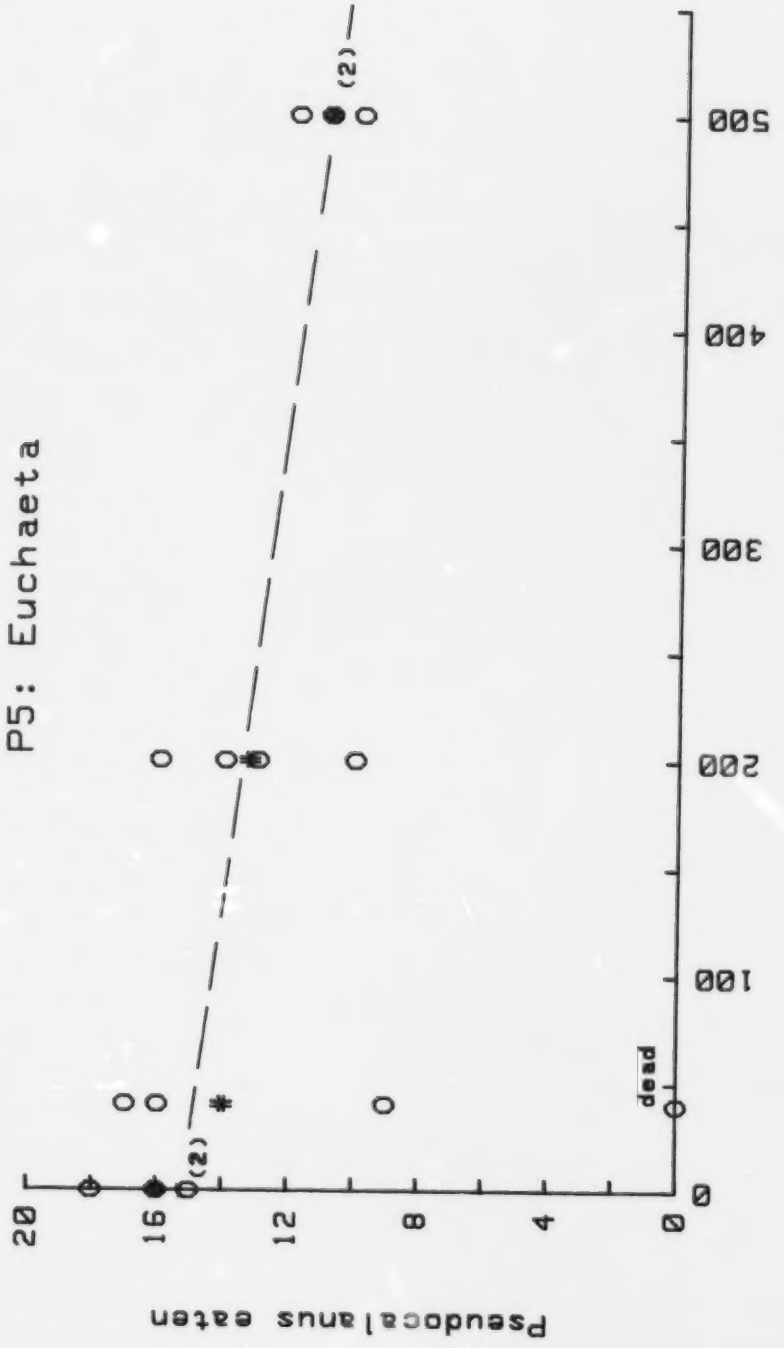

Figure 6. Experiment P5: effect of tailing on Euchaeta predation

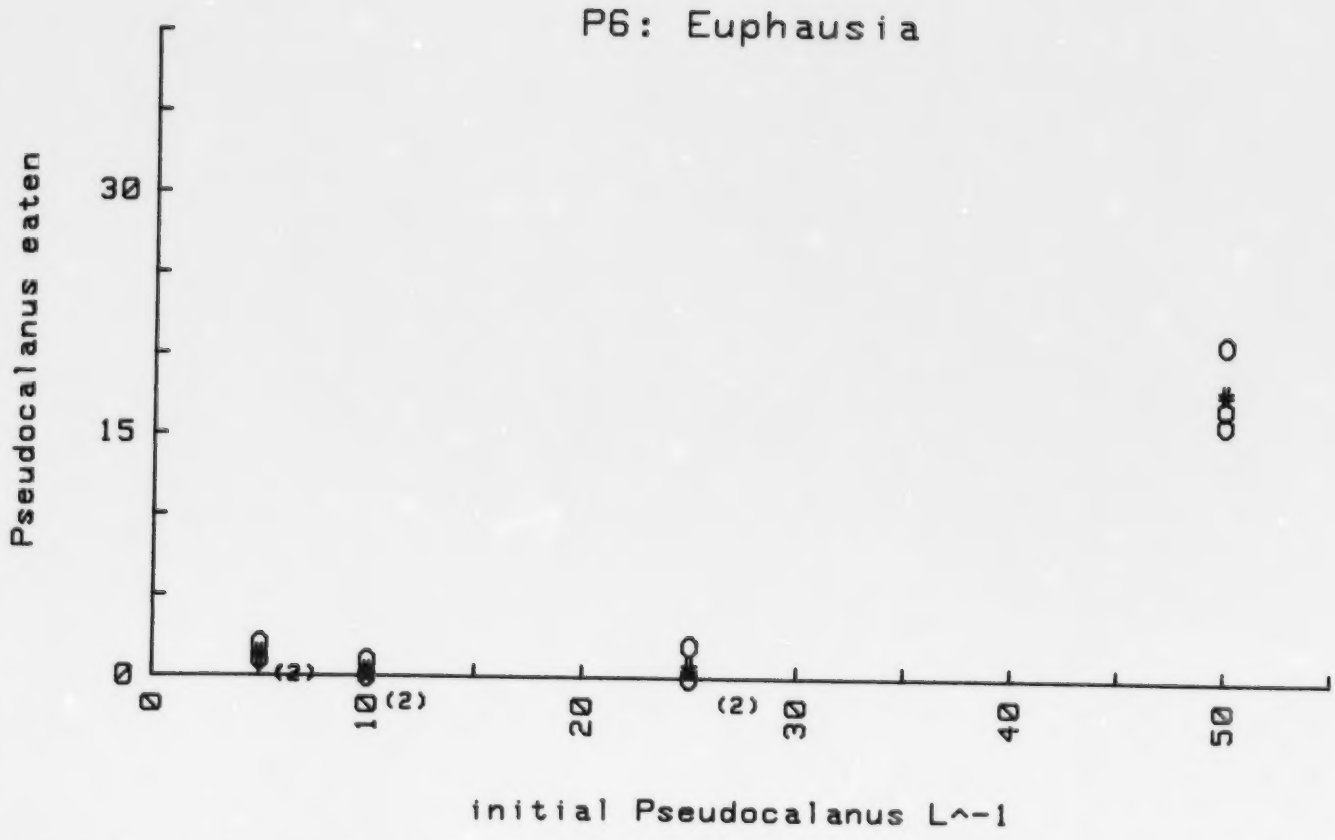

Figure 7. Experiment P6: Functional response of Euphausia pacifica to various concentrations of Pseudocalanus sp.

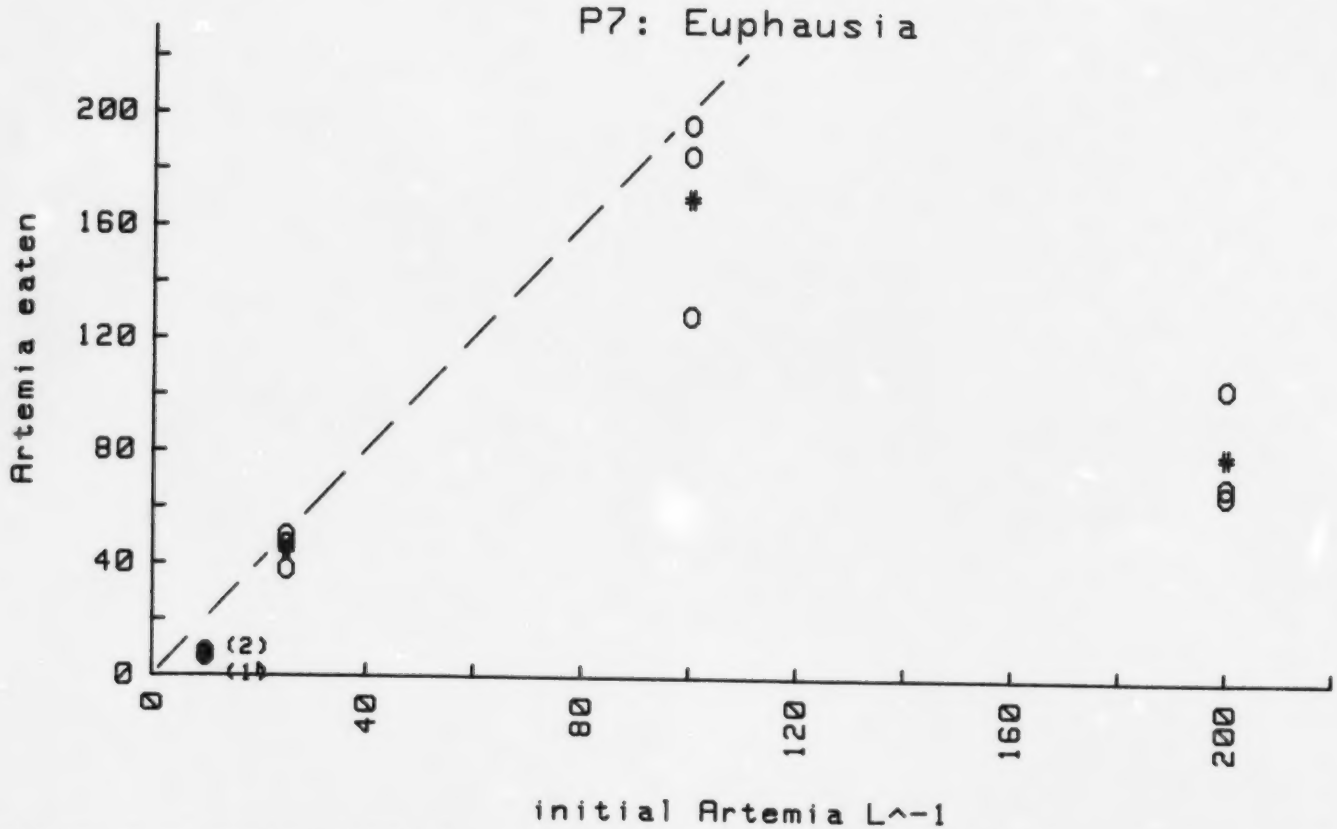

Figure 8. Experiment P7: functional response of Euphausia to various concentrations of Artemia nauplii. The dotted line represents 100% captured in 24 hr from 2 L.

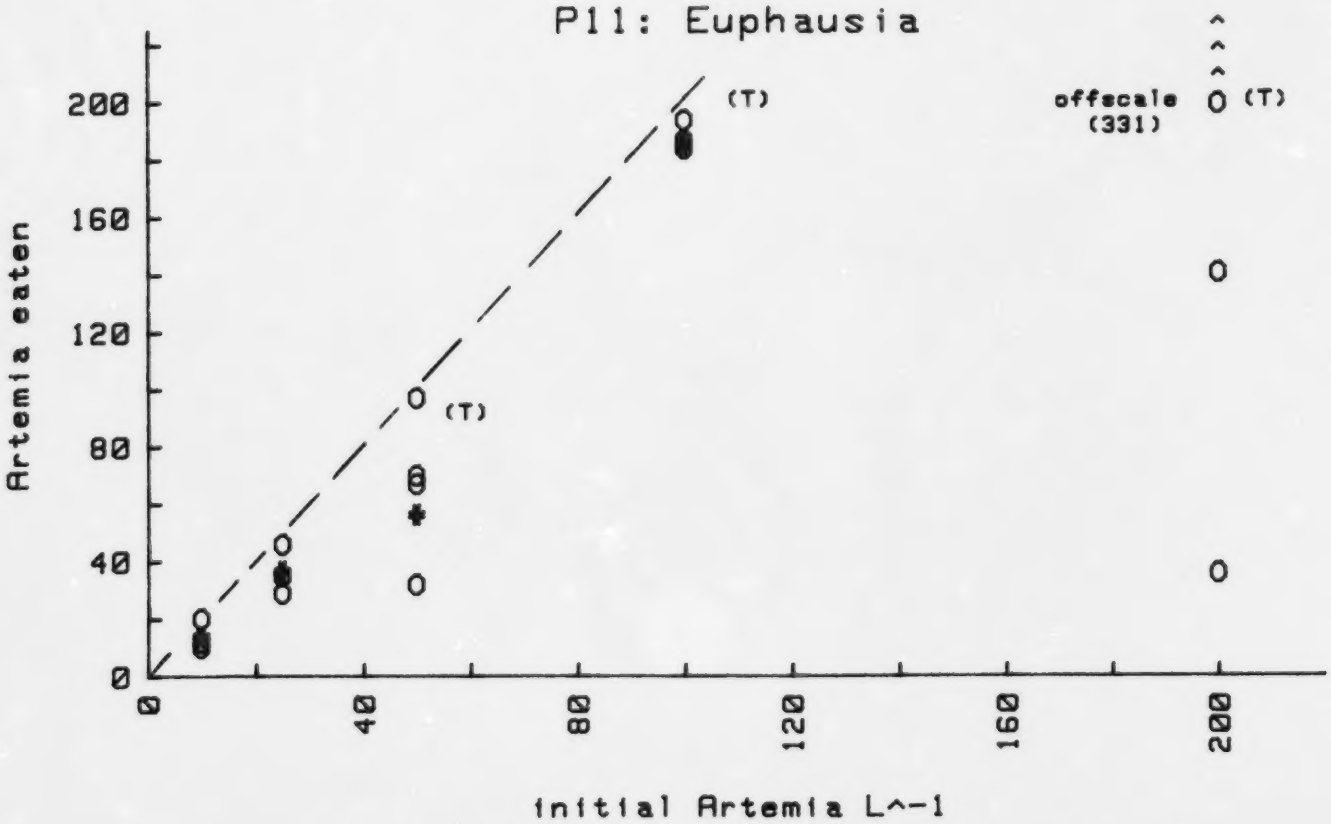

Figure 9. Experiment P11: effect of tailing on Euphausia predation rate.

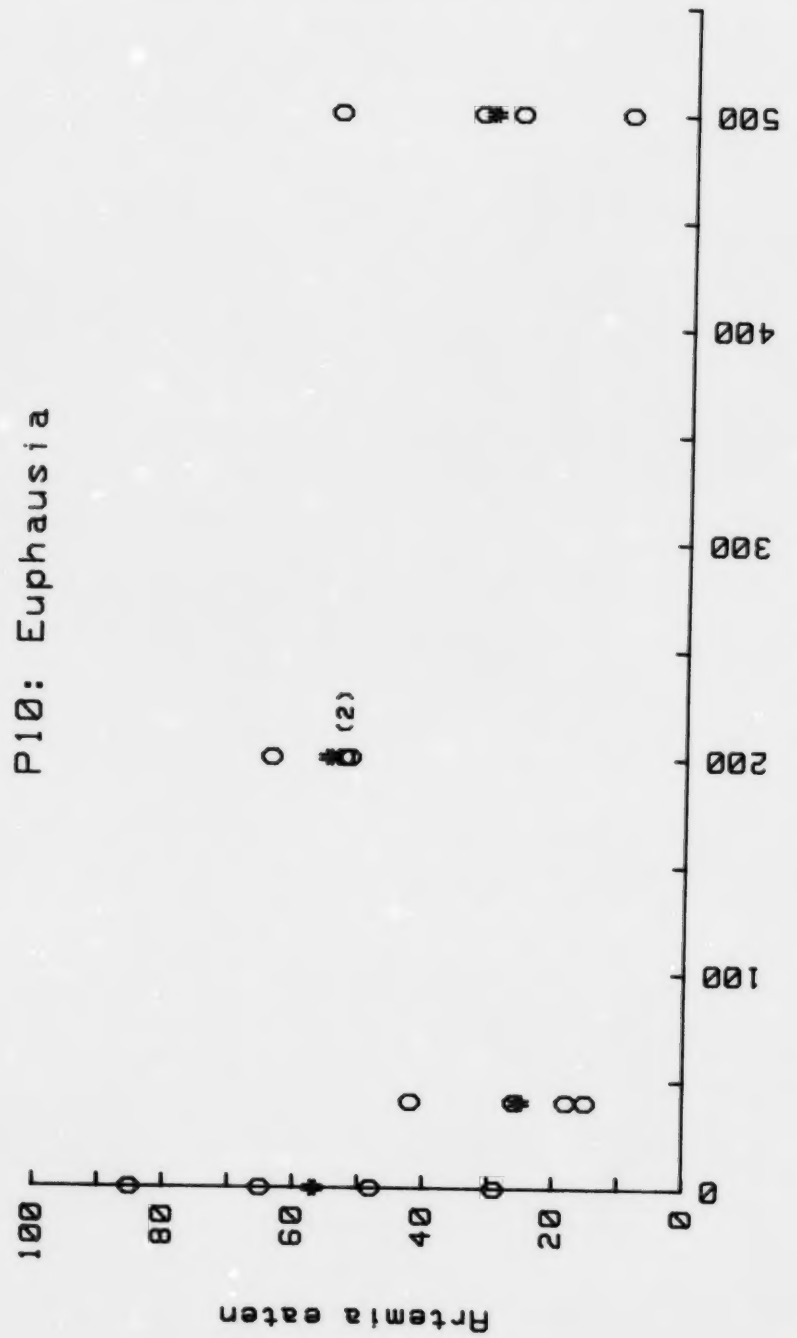

Figure 10. Experiment P10: effect of tailing on Euphausia predation.

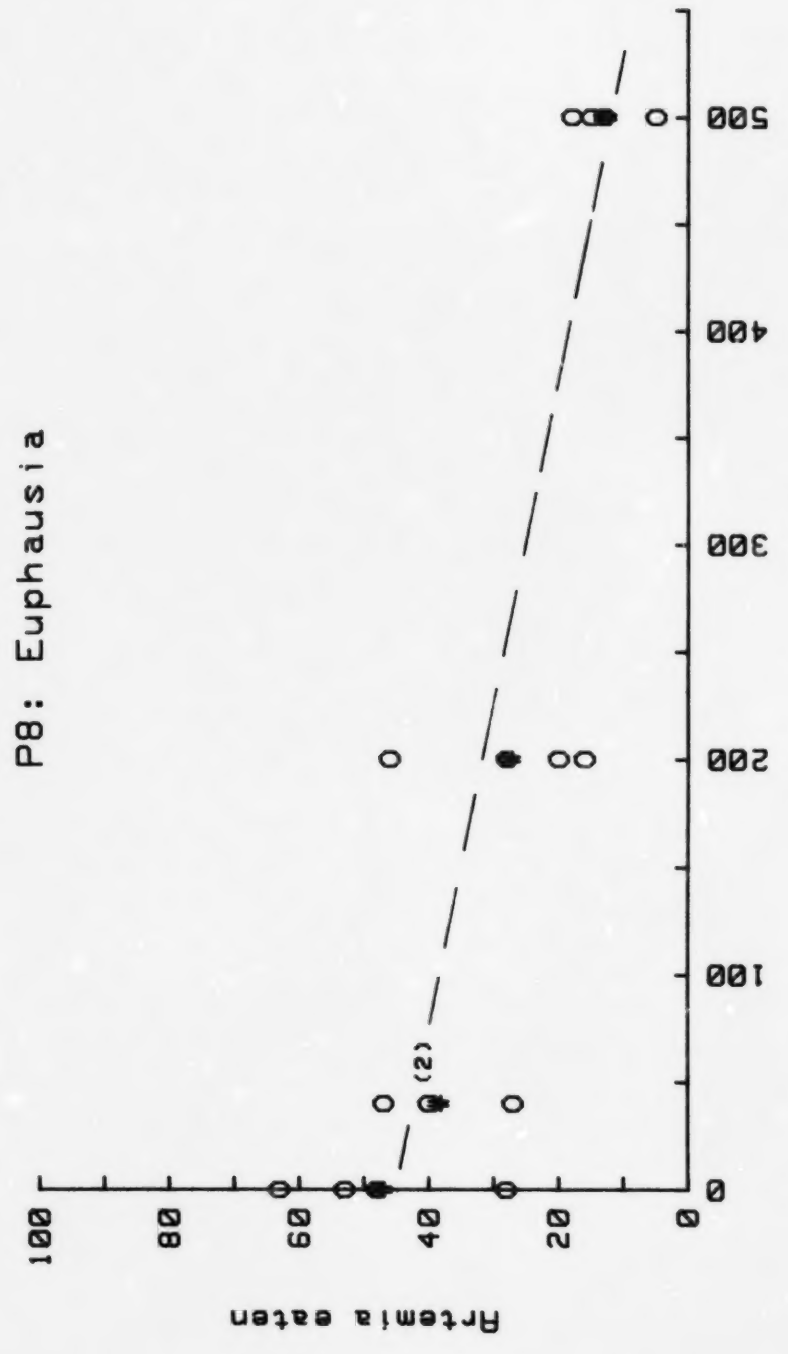

Figure 11. Experiment P8: effect of tailing on Euphausia predation rate.

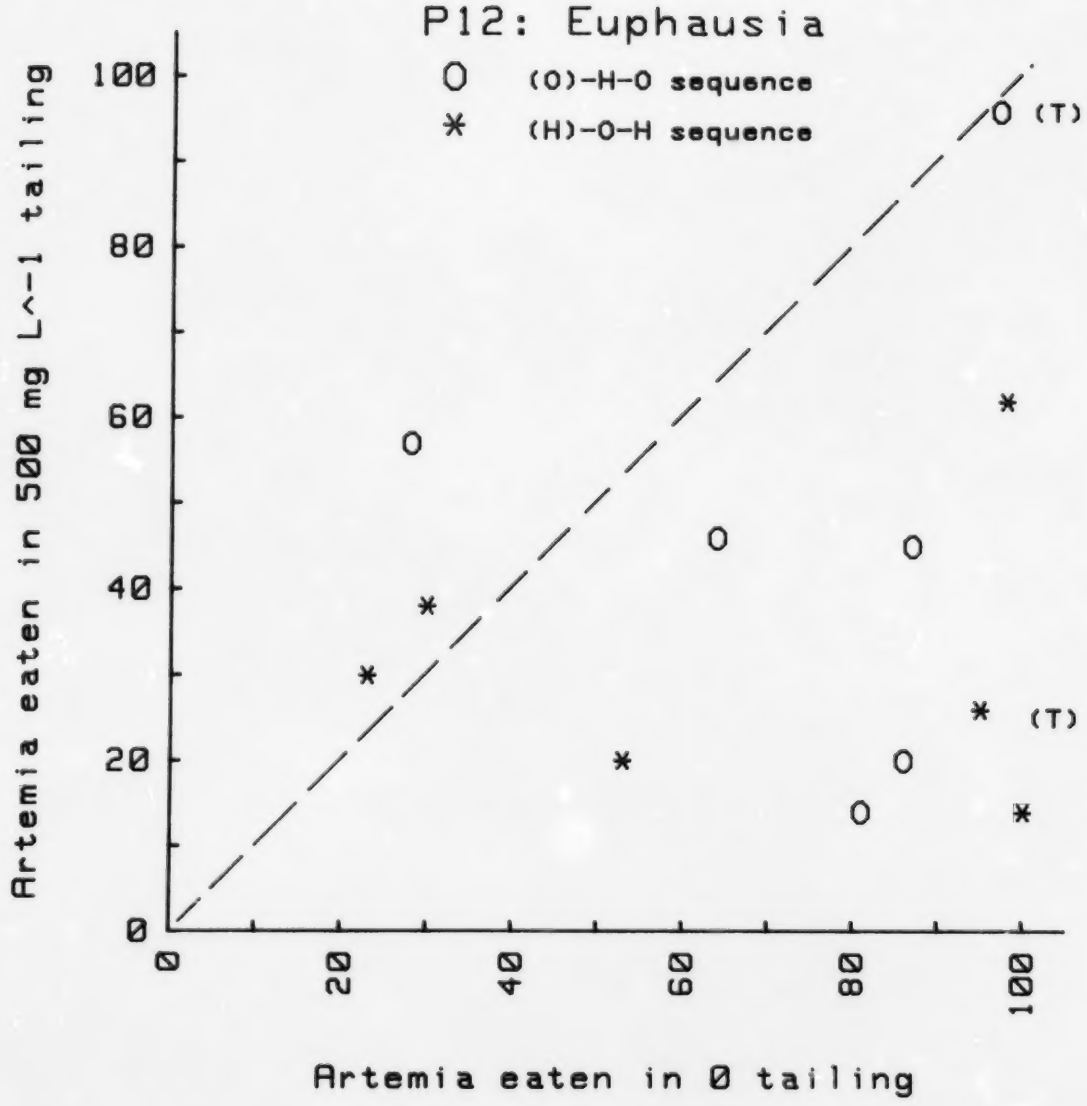

Figure 12. Experiment P12: feeding rate of individual Euphausia in high tailing and in zero tailing. The dotted line represents equality.